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Electric Railway Traction

Systems of Electrification

NOTWITHSTANDING the conclusion of various authorities that railways should be electrified for direct current working, there still exists some diversity of opinion outside official circles on this question of the most meritorious system. While Great Britain and France tend to favour the d.c. method, Switzerland, Austria and Germany are staunch supporters of the single-phase a.c. method. The United States is extending single-phase operation and is at the same time electrifying railways for 3,000-volt d.c. working. Italy is disposed to abandon further three-phase projects for d.c. schemes, and Spain is also showing a preference for the use of d.c. The case for d.c. seems to be that it is eminently suitable for suburban railways, and for companies proposing to utilise an industrial electricity supply of 50 or 60 cycles frequency.

With a few exceptions a.c. railways require a low frequency supply and hence they must provide for their own power generation and distribution, or else be burdened with expensive and complicated converting equipment. In Switzerland the railways are more completely electrified than anywhere else in the world and, considering the arduous nature of the work performed by single-phase locomotives in that very rugged country, it is difficult not to believe that the single-phase system has shown itself to be the best and most thoroughly tested of all systems for heavy main line work. Specially provided sources of supply are, however, tapped by this and by other particularly successful single-phase railways. That it will not always be necessary for single-phase railways to receive their energy at a low frequency we can readily believe, for success has already been achieved with mixed systems, such as the Kando, where the main supply is single-phase at an industrial frequency.

The three-phase railway is confined almost exclusively to Italy, but here it has given satisfaction for many years. Comparatively high voltages and the simplest imaginable substations are points in favour of this system, but two overhead lines must be provided for each track, and this may become a serious disadvantage where there is much complicated track-work. The constant-speed peculiarity of the three-phase locomotive has given rise to unfavourable comment, but it is to be remarked that, from the purely operating point of view, a locomotive which can be relied upon to haul heavy loads as fast as light loads over all sections is to be preferred to one having the well-known d.c. series characteristic. With a very heavy train, the d.c. locomotive is bound to lose time which a three-phase locomotive would have no difficulty in keeping. The single-phase locomotive with extra-voltage transformer tappings is the only one which can be " thrashed " like a steam engine when time is lost, and the d.c. locomotive is as inflexible in the matter of picking up time lost by signal checks as the three-phase locomotive, unless its normal schedule is a particularly easy one which permits long periods of coasting. Double heading with three-phase locomotives calls for special precautions, which are not necessary with single-phase or d.c. locomotives, and three-phase multiple-unit working is, in general, unsatisfactory.

Suburban Conversions

THE beneficial results obtained from the conversion from steam to electric traction of suburban lines with dense traffic are, and always have been, beyond dispute. But that the increased traffic and revenue, which the faster, cleaner, more frequent and more regular train service permitted by electric operation, are now being assessed at something like their true worth is strikingly evidenced by the happenings of the present month. Commencing in a modest way with the two-mile extension of the Southern Railway from Bickley to St. Mary Cray, electric operation over which was inaugurated on May 1, the second half of the month presents the opening of two important conversion schemes on the Continent, the reason for this time in both cases being the summer timetables, which are due to come into force on May 15. On the Danish State Railways, an electric service commences on that date on the whole of the Copenhagen suburban system, with the exception of the Hellerup-Holte line, conversion work on which is now in progress. Over the 17 route miles now electrified, trains will run at 15-min. intervals during the day, and at 10-min. intervals during rush hours, but in view of the popularity of the Frederiksberg-Klampenborg service, which has been open since the beginning of April, it is to be doubted whether the present total of 62 motor coaches and 32 trailers will be found sufficient.

Another suburban extension of note is that from Rotterdam to Dordrecht, on the Netherlands Railways, a distance of 12 miles, all double track. The Netherlands Railways authorities have also announced that a further extension of the Amsterdam-Rotterdam-Dordrecht electrified system will be made from Rotterdam to the Hook of Holland, and it is anticipated that this 17½-mile stretch will be operated electrically by next year. The Dordrecht extension is yet further proof that once a railway has taken up electrification there is no going back, and that the trepidation which may have been felt prior to embarking upon the initial venture has given way to something like impatience until further sections have been converted. That staunch upholder of suburban electrification, Sir Herbert Walker, has recently stated that as a result of the better services provided by electric trains, housing estates have grown up like mushrooms along the Southern Railway suburban system, and that something like 250,000,000 passengers are carried every year by that company's electric trains. In a proportionate degree, such results can be attained elsewhere by a timely electrification, *i.e.*, before a more progressive rival company has taken advantage of this form of traction, and moved the centre of population on to its own system and gained a large increase in revenue.

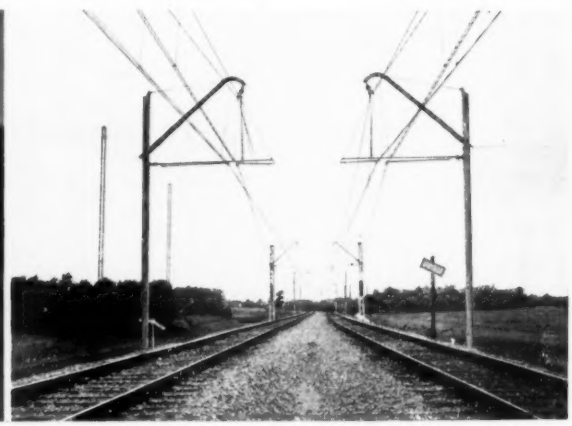
COPENHAGEN SUBURBAN SYSTEM

Partial electric operation to be augmented to full service in May

ON April 3 the first portion of the Copenhagen electrified lines, the division from Frederiksberg to Vanlose, Hellerup, and Klampenborg, was opened to public service. Over this 9¾-mile line, a special train containing representatives of the Danish Parliament, the municipalities served, the State Railways, the contractors, and the press, made the inaugural run in 17 min., and after the return to Frederiksberg the regular public service began.

A temporary timetable with only a few more trains than before will operate until the advent of the summer timetables on May 15, which date will also see the inauguration of electric working between Copenhagen Central, Hellerup, and Klampenborg. The Frederiksberg-Klampenborg service has attracted great public interest, and on the first Sunday after the opening, the 20 special trains scheduled proved inadequate to cope with the traffic, and practically a 15-min. service had to be run throughout the day. It is not expected that the line from Hellerup to Holte will be opened to regular electric service until the end of the present year, but on its completion the total electric route mileage will be 23·7, and the track mileage about 54.

New station at Frederiksberg



Overhead construction on suburban lines

The opening of the Frederiksberg-Klampenborg section was scheduled to take place on February 1, but during the trial runs a serious mishap took place, and 330 yd. of overhead wiring were torn down, necessitating considerable alterations to the wiring system and the pantographs. The public service has so far operated without any irregularities, but the timings are easy, 25 min. being allowed for the 9¾ miles inclusive of seven intermediate stops. It is, however, intended to build one, and possibly two, new stations, and probably stops at these stations will be made without increasing the overall time. Trial runs between Osterport and Hellerup began on April 14, and the stretch from Osterport to Copenhagen Central, including the complicated sidings, washing plant, and sheds at the latter place, have just been completed.

A general description of the electrified lines and their equipment was given in the issue of the *Electric Railway Traction Supplement* for October 27, 1933, but the following further details are now available. When the complete scheme is finished about the turn of the year, the 1,500-volt d.c. contact line will be fed from four sub-stations, containing a total of nine mercury-arc rectifiers of the steel-tank type. The standard rectifier unit is of 2,500 kW. capacity, and Enghave and Hellerup stations will contain three units, Flintholm two, and Holte one; all will be remotely-controlled from Enghave substation. The rectifier groups are fully automatic, and if any fault should occur on the system the adjacent rectifier group is unable to start. But the automatic installation causes three tries to be made at one-minute intervals and, if the fault has not by then been remedied, the rectifier is definitely cut out. Each sub-station, however, contains a control room provided with the necessary apparatus and indicator lamps for manual control on the spot, and in addition to the main apparatus, a small transformer for feeding the auxiliary motors and lighting circuits is installed, and a battery provided for emergency lighting.

Two 650 h.p. double-bogie motor-coaches, with a trailer between, form a normal unit, but six-car trains are run during the peak periods. The motor-coaches scale about 49 tons tare and the trailers 37 tons, giving a ratio of 0·575 ton per passenger for the seating accommodation of 235. The order for the complete electrical equipment for the rolling stock was given to the English Electric Company on the understanding that only 48 traction motors, and the whole of the electrical equipment for the trailers and for twelve motor-coaches, would be built in England, the remainder being constructed to English Electric drawings by the A/S Titan, of Copenhagen, and the firm of Th. B. Thrige, of Odense. All-electric multiple-unit control with automatic acceleration is embodied, and the maximum starting acceleration is approximately 2·0 m.p.h. per sec. The cars themselves have only one class of accommodation, and were constructed by A/S Frichs and the Scandia Car Works; they were described in the issue of this Supplement mentioned above.

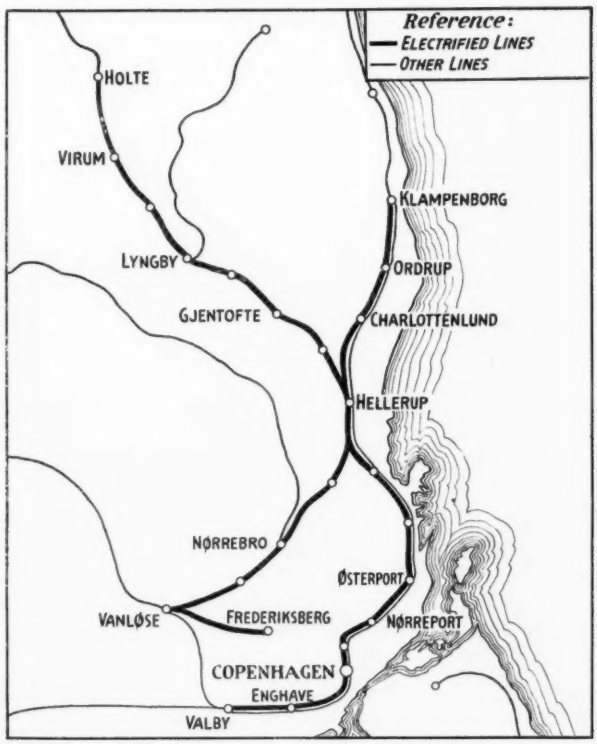
The overhead system for each track consists of two copper contact wires of 100 sq. mm. section, supported at 33-ft. intervals by stringers dropped from a bronze catenary of 70 sq. mm. section. In order to decrease the

electrical resistance on certain sections of the line, a further copper cable with an area of 240 sq. mm. is provided. The overhead equipment of each track is entirely separate, as may be seen from the accompanying illustration. The contact wire is staggered $13\frac{3}{4}$ in. each side of the centre line to obviate the wearing of grooves in the pantograph strip, and the overhead equipment as a whole is supported by steel masts placed at intervals of 262 ft., except at

Interior of one-class electric train. Danish State Railways

stations and in yards, where cross catenaries supported by tall steel lattice posts are used.

Although the signalling and many of the stations on the electrified area have been brought up to date within recent years, a good deal of work has had to be carried out in order to fit them for electric traction. Hellerup station already had colour-light signalling with platform indicators and electrically-operated switches, and colour-light signalling is being extended to the whole system, although it will be automatic type only at certain points. From May 15, a normal 20-min. service will be run over the electrified lines, with a 10-min. service during the



Map of Copenhagen electrified lines

rush hours and on Sundays. This will mean that for the rest of this year, *i.e.*, until the conversion of the Hellerup-Holte line, the Copenhagen-Hellerup section will be operating at its maximum capacity, for the double track between these two stations will have to carry stopping and semi-fast trains from Copenhagen to Holte and beyond, in addition to the electric trains. Steam trains for beyond Klampenborg will continue to operate on separate tracks.

Although the locomotives and cars hitherto in use on the Copenhagen suburban system are quite modern, their value will not need to be written off against the cost of electrification, as they will replace the old stock now in use on the lines in Zealand and Jutland. The stock released by electrification will enable the almost virtual abolition of four-wheeled carriages in Denmark.

Electric train at Norrebro station

Electric train leaving Klampenborg for Frederiksberg

MODERN DEVELOPMENTS IN TRACTION MOTOR DESIGN

An authoritative review of progress during the past decade

By G. H. FLETCHER, M.I.E.E.

ALTHOUGH in outward appearance there is little difference between the traction motor manufactured to-day and that manufactured, say, 10 years ago, steady developments have taken place in detail design, tending to reduction in cost and weight, and to reducing maintenance costs to a minimum. These improvements may be considered under three separate heads:—

1. *Electrical.*—(*a*) Greater ratio of active to inactive material, (*b*) improved commutation, and (*c*) improved dissipation of heat generated by employment of improved ventilating methods.

2. *Insulation.*—(*a*) Use of better insulating materials developed to withstand much higher temperature rises and treated to withstand moisture.

3. *Mechanical.*—(*a*) Improvements in mechanical design, and (*b*) the use of alloy or treated materials.

Electrical Improvements

What has been regarded as a standard armature utilises a core built up of punchings with rectangular slots into which rectangular sectioned coils are inserted. These coils consist of a number of copper straps side by side in the case of large motors, and round or rectangular wires in the case of small motors. With such a construction the tooth is necessarily wider at the top than at the bottom, and therefore the flux tends to be strangled at the root of the tooth.

Obviously a much more economical construction would employ a substantially parallel tooth, with a view to

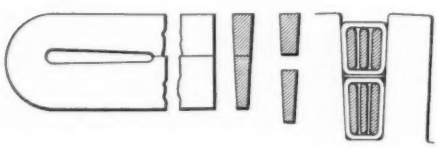


Fig. 1—Taper conductor and slot

obtaining a uniform flux density throughout its length. This, however, results in a slot which is wider at the top than at the bottom, and which requires coils, the top and bottom portions of which differ in dimensions and are made to fill the tapered slot. The problem of designing a satisfactory coil of this kind has been solved.*

The conductor is prepared from copper strip of taper or trapezoidal section. For a normal two-layer winding the strip is equal in width to the net depth of slot copper and is a little more than half the length of the required single turn. This strip is sheared throughout its length as shown in Fig. 1, and forms the two sides of the conductor of equal cross sectional area, but of different width in virtue of the taper. The bifurcated strip is formed into a coil in the well-known manner of bending the legs in parallel planes, so that two straight sides with suitable end connections are formed. The conductor is insulated and taped into a coil in the usual way.

By the adoption of a winding of this type it is possible to obtain from 10 to 20 per cent. more copper in an armature core of a given diameter and length for the same flux densities, but in addition to this, as the slot portion of the coil is in the form of a wedge, it is possible to drive the coil in tightly and avoid vibration of the coil in the slot, and repairs may also be effected more readily, as when the coils are raised slightly they may be easily lifted from the slots.

An additional advantage is realised on high-tension machines where a large number of narrow commutator segments is required, as the saw-cut in the neck of the commutator bar necessary to introduce a conductor of rectangular section, reduces the thickness of copper at the bottom of the neck and makes it mechanically weak, as shown in Fig. 2. With the tapered conductor, however, as the slot is narrower at the bottom, the wall on each side of the conductor is substantially parallel, and will be thicker and stronger than with a parallel conductor. The reactance voltage for a winding of this type is also reduced because, as the slot is wider at the top, the leakage flux is reduced, and better commutation may therefore be obtained.

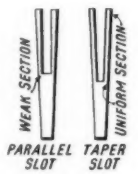


Fig. 2—Diagram of commutator necks

One of the most important considerations in the design of a traction motor is that of commutation, and the ability of the motor to operate without flashover under sudden fluctuations or interruptions of line voltage, and all modern motors are tested for these contingencies by subjecting the motor to sudden interruption and re-application of voltage at any speeds shown on the characteristic curve. When a voltage is suddenly applied to a series motor after an interruption, as a substantial proportion of the field circuit is solid material, the interpole flux, due to the generation of eddy currents in the circuit, builds up more slowly than the reactance voltage of the armature, and consequently for a fraction of a second the reactance voltage of the short circuit coils is not fully compensated.

On a large machine, therefore, it has been found desirable to laminate the interpoles so as to reduce the damping effect to a low value, and if in addition the interpole air gap is suitably proportioned, it is possible to interrupt and re-establish the current at any service speed without causing any flash which would damage the commutator.

Further improvements in commutation have been obtained by the use of a magnetic shield. The commutator flux under the interpoles is to some extent affected by the

Fig. 3—Modern type of brush holder

* British Patents Nos. 189,861 and 349,975.

adjacent main poles. On series motors which always run in one direction, the effect can be allowed for in the design, but in other cases, particularly with compound-wound machines, which work under a variety of main field conditions, for any value of armature current the influence of the main poles is not constant, and the best that can be done is to reduce the interference to a minimum. A magnetic shield has been used for this purpose on certain machines, and consists of a ring of magnetic material encircling the tip of the interpole and reducing the penetration of main pole flux into the zone on the armature enclosed by the ring.

In the question of collection of current from the commutator, mechanical considerations are quite as important as reactance voltage, and the brush holder and its support should be substantial and rigid, in order to avoid any relative radial movement of the brush box to the commutator. The carbons should be pressed to the commutator by springs with sufficient tension to keep the carbons in contact under the very severe conditions met in service, particularly where the motor is suspended on the axle, and subject to severe impact from the rails and vibration from the gears. At the same time, it must be accessible and is preferably provided with a hold-off catch so that the carbons may be withdrawn for examination by one hand. The tension device should have a minimum of sliding surface in order to eliminate friction and provide freedom of movement (see Fig. 3).

Ventilation Developments

The earliest traction motors were totally enclosed, as the conditions under which a motor operated, that is in an exposed position a few inches from the track, were considered too severe for an open type motor. The difficulties to be met are due to water, snow, dirt and brake shoe dust. It has been found by experience that the impregnation of field coils in hydrolene gum, together with certain special precautions at the point where the leads leave the coil, renders the coils quite immune from any ill effects from water or moisture.

With regard to foreign matter, it is considered that if the motor is to be of the open type it is better to pass air through it at as high a velocity as possible, so that any foreign matter which enters may be carried through and expelled. In this connection it is important that all air passages should, as far as possible, be smooth and without air pockets in which the air would eddy and deposit dirt. It is obvious that the most vital part of the machine from this point of view is the commutator and collector gear. Dirt may find access to the brush gear and interfere with the operation, or conducting material may cover the creepage surface, either of the brush holder or the commutator and so make it possible for a flashover to take place at these parts.

In general, however, even for 1,500-volt operation, there are a number of methods which have recently been adopted to meet any difficulties which may arise due to these conditions. The brush holder may be provided with a cap, which completely encloses all the working parts and so protects them from dirt or foreign matter, and creepage distances may be increased sufficiently to give a satisfactory margin.

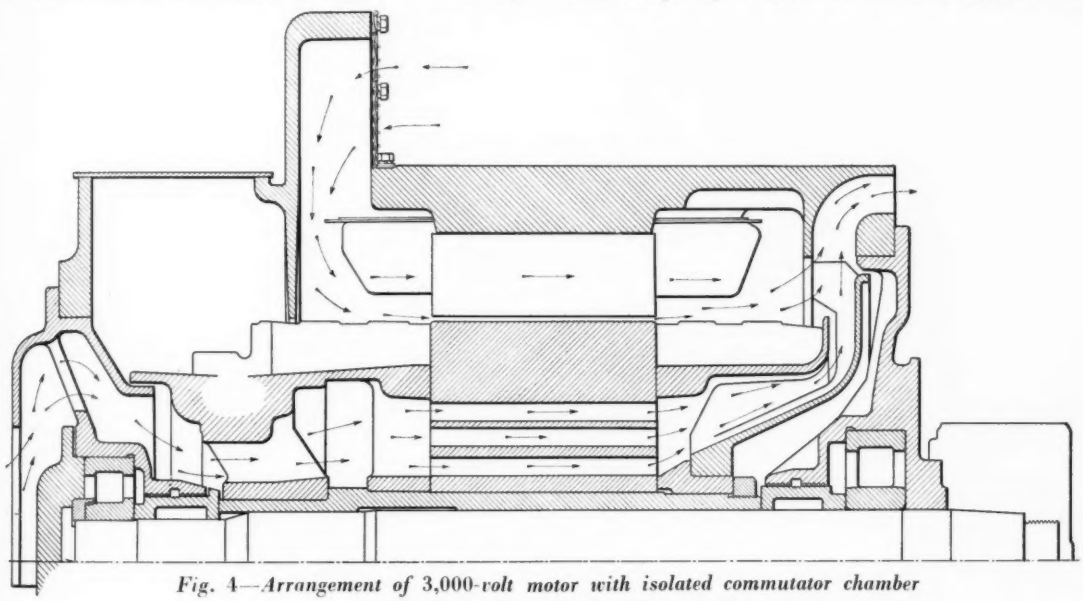


Fig. 4—Arrangement of 3,000-volt motor with isolated commutator chamber
(Section through corner of yoke to show air inlet)

Another method which has given satisfaction in a motor operating on 3,000 volts has been the provision of an enclosed chamber for the commutator and brush holders, the air entering through openings behind the commutator chamber for cooling the field coils and periphery of the armature, and a parallel circuit being introduced through openings in the end housing which connects it immediately underneath the commutator. In this way no air was permitted to pass over the commutator or the brush gear, as may be seen from Fig. 4.

Perhaps the most satisfactory way for self ventilated motors is to connect the inlet to the motor by means of a flexible air duct to a duct in the motor-coach, which permits air to be taken either from the roof of a motor-coach, suitably louvred to prevent the ingress of rain, or from the inside of the motor-coach itself. This is a method which has been used quite successfully on a number of 1,500-volt motors.

Insulation Improvements

During recent years much progress has been made with what is known as Class B insulation which chiefly consists of mica or asbestos. In many of the earlier armatures, although mica wrap was used for insulating the slot

portion, and paper and mica taping used for insulating individual conductors, a large proportion of Class A material was used, such as cotton tape for finally taping the armature coil and field coils, but it was found that cotton tape deteriorates, even under moderate temperatures, over a period of years. This ageing can certainly be retarded by impregnating the material periodically with a suitable varnish or compound. As a matter of fact, gum impregnated tape will withstand a moderate temperature almost indefinitely, but while this can be used for field coils and may be regarded as a very satisfactory insulation for temperatures below 100 deg. C., it is not possible to treat armatures in the same way.

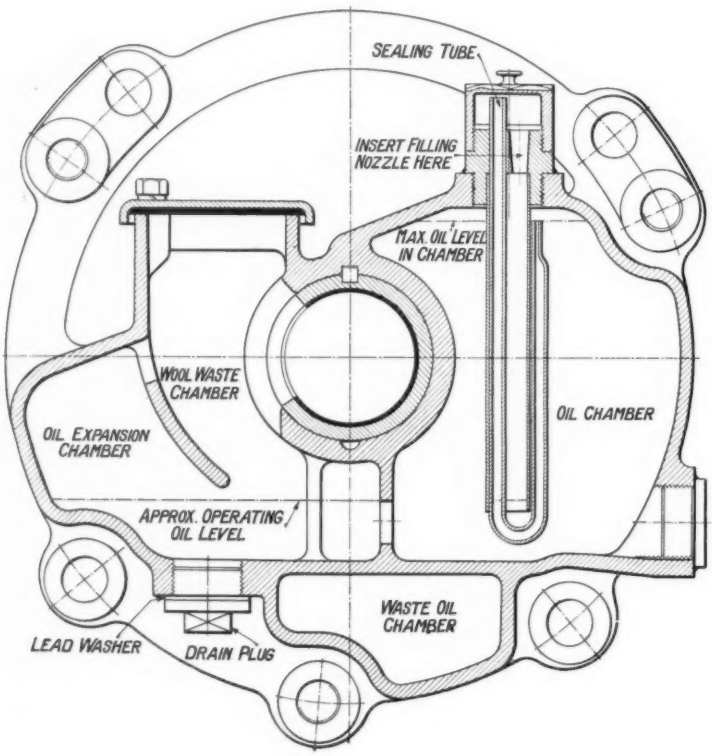


Fig. 5—Lubrication of traction motor sleeve bearings

Great developments have been made in asbestos insulation. Asbestos tape may now be obtained closely woven, thin, and mechanically strong and free from the impurities which some years ago rendered it unsatisfactory for insulating purpose. One difficulty with asbestos is the fact that as it is composed of mineral fibres, it is not possible to impregnate the individual fibres, but only to fill the interstices between the individual fibres with some suitable impregnating compound as readily as when vegetable fibres are used. It is, nevertheless, a suitable material for supporting the turns of field coils where the di-electric stress is low, and for taping the outside of the coils where the chief purpose is to bind the mica insulation in position.

Recently, round and rectangular conductors have become available, covered with an asbestos felting which is nearly as strong as cotton covering, and which takes up as little if any more room. Suitably impregnated, this wire is suitable either for shunt coils or for armature coils, and it is comparatively unaffected by high temperatures. It constitutes a very considerable improvement on D.C.C. wire which previously found almost universal use. At the present time, owing to the development of Class B insulation, international rules have been amended to permit its use for temperatures up to 150 deg. C. Considerable experience has shown that these temperatures are very conservative, and there is no doubt that in the near future temperatures of much higher values will be adopted for the use of Class B insulation. Another development which has taken place during the last 10 years is the bakelising of the slot portions of armature coils which, together with the use of Class B insulation, makes that portion of the coil practically imperishable.

Mechanical Improvements

The improvements which have been made in the mechanical design of traction motors have reference to the elimination of mechanical faults and to the reduction of maintenance charges. Some of the most important changes affect the motor bearings as detailed below, but attention also has been given to the use of the most suitable materials for the armature and yoke parts. Commutator construction, design of ventilating fans, and brush gear, represent a few further details which have been given special attention.

Axle bearings are usually comparatively lightly loaded, and run at fairly low peripheral speeds; consequently they should give a good life without much attention. The armature bearings, on the other hand, are much more heavily loaded, and run at higher speeds. Until fairly recently, the sleeve bearing was almost universally used, lubricated either by wool waste or cotton pressed against the journal, and which syphoned up oil through a window in the bearing, or in some cases by means of oil rings. The waste-lubricated bearing has been quite successful on many railways, and on one particular line, where a large number of motors are in service, the bearing failures work out at not more than 1 in 7,500,000 motor miles. The bearings are usually composed of high quality bronze with a very thin lining of white-metal, the thickness of which must be less than the airgap of the machine, so that in the event of the bearing failing, and the white-metal running out, the journal runs on the brass before the armature fouls the main poles.

More recently there has been a definite move towards the use of roller bearings. The advantages which have been expected are as follow:—

1. Reduction of bearing failures.
2. Reduction in maintenance costs due to the extension of the period between lubrication.
3. Maintenance of better alignment between gears due to the absence of bearing clearance.

The cost of a roller bearing is appreciably more than that of a sleeve bearing, but against this cost can be offset the saving on lubrication, since roller bearings need attention only once in four months, compared with the seven to ten-day period for sleeve bearings.

A number of methods have been adopted whereby the period between lubrication of sleeve bearings can be extended. One of these methods is illustrated in Fig. 5, which shows a bearing constructed on the principle commonly used for supplying water to chickens. This is a type which has been used to a considerable extent in the United States, and apparently with success. It will be seen from the illustration that the housing is provided with the usual wool waste chamber, and that the oil chamber is very much larger than in the case of the ordinary wool-

lubricated bearing. By means of the special filling and sealing tube it is possible to fill this oil chamber to a considerable height above the normal running level of the oil. The level of the oil in the wool waste and expansion chamber is determined by the hole which connects this chamber to the oil chamber. Thus it will be seen that this bearing has a double advantage over the ordinary type, in that not only is it capable of holding a very large quantity of oil, making it possible to extend the oiling period considerably, to from one to three months, but, in addition, this oil is maintained at a fairly constant level, the only variation being that due to movement of the car. When oil is being poured through the filling tube the air above the oil level is forced out through the U-tube until the oil reaches the point of maximum level, when the oil is forced through the U-tube and seals the chamber One difficulty experienced in connection with sleeve bearings is that the surplus oil from the bearing does not return to the oil well, but in many cases passes through an opening in the bearing housing and falls to the track.

With a ventilated motor, there is a danger of air passing through the waste oil opening in the yoke carrying the oil past the oil thrower into the motor. This gives rise to considerable trouble, particularly if the oil finds access to the commutator or to the brush gear. To provide against this difficulty a special sealing device has been developed which is in the form of a malleable iron U-piece. The surplus oil must pass through the oil seal in its passage to the outside opening. In so doing it forms an oil seal against the incoming air, and by this means it is possible to allow oil to pass out of the housing at the same time preventing air from passing through.

One of the chief difficulties with a self-ventilated motor is that of preventing the access of brake shoe dust to any vital part. Much of the brake shoe dust is colloidal in form and can easily find access through even the finest openings. In a number of cases, large quantities of dust have ultimately found their way between the end of the armature core and the coil support. It is not possible to depend upon pressure between the two coil supports to avoid completely any ingress at this point, owing to the fact that punchings vary in thickness, and the total iron may be different at two points diametrically opposite. This has been cured by making a complete seal at this point by taking the last lamination, which is thicker than the standard lamination, and spinning it over the end of the coil support, thus making it a complete seal, as shown in Fig. 6.

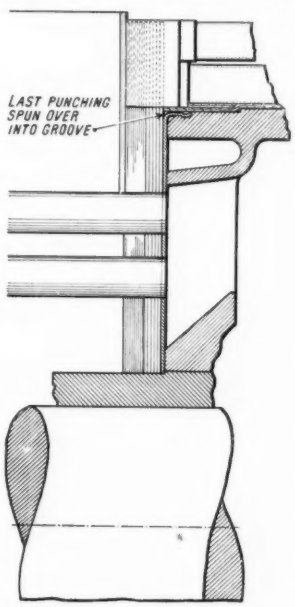


Fig. 6—Method of sealing armature and coil supports to prevent ingress of foreign matter

Shaft breakages, which were once fairly common, have been reduced to negligible proportions. This improvement has been brought about by attention to design and the use of alloy steels. The improvement is more noteworthy because failures have been eliminated in spite of the increased stresses imposed. On the modern armature shaft where changes of section occur ample radii are provided to avoid the concentration of stress that would otherwise occur at the section change. Further the alloy steel gives an additional factor of safety in that the endurance or fatigue value and resistance to impact load are substantially increased over the hard shaft steel which was at one time used.

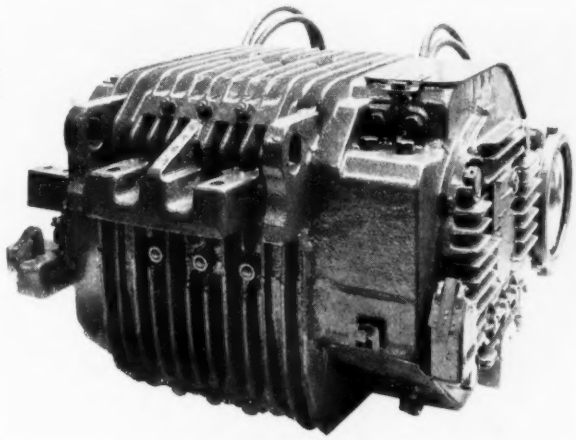


Fig. 7—Metro-Vick nose-suspended motor as used on the London-Brighton section, Southern Railway. The ribs increase the surface 80 per cent. above the normal

Such developments as have been described above have been successful not only in increasing the actual life of a motor, but also increasing the period between successive overhauls. Although it has been the practice on many railways to overhaul a motor about every 18 months, there are numerous cases in which motors have been in service for at least three years without any attention other than the lubrication of the armature bearings. This is a noteworthy achievement considering the very severe conditions under which the motor operates, having regard to impacts, vibration from gears, exposure to variable climatic conditions and heavy overloads.

Southern Electrification

IN view of the inauguration on May 1 of electric traction from Bickley to St. Mary Cray—the first portion of the conversion of the Sevenoaks lines—some of the statements of Sir Herbert Walker in an article published in *The Financial Times* are of much interest. Largely as a result of the better travelling facilities offered by electric trains, new housing estates have sprung up very rapidly alongside the suburban system of the Southern Railway, and that company's electric trains now carry 20,000,000 passengers every month of the year over a route mileage which now amounts to 361. During 1933, 2,000,000 more passengers were carried on the Coulsdon-Worthing section than in the previous year under steam operation, representing an increase of 33 per cent. Moreover, over the Whitsun holiday period of last year, 129,000 passengers were taken to Brighton, an increase of 79 per cent., and in the first year of electrification the season ticket holders on the Brighton section increased by 6 per cent. Since the amalgamation of 1923, the Southern Railway has spent £11,000,000 on electrification programmes, including the provision of colour light and power signalling on some of the most densely trafficked lines.

ITALIAN RAILWAY ELECTRIFICATION

Opening of Bologna-Florence Direttissima forms the prelude to a comprehensive extension of electrification on the Italian State Railways

New station at Prato, the junction of the Bologna-Florence Direttissima with the old line via Pracchia

THE abundant water power available in Italy, coupled with the complete lack of indigenous coal, were the chief considerations which, as far back as the 'nineties of last century, caused the Italian Government to give serious thought to electrification. A third, and not much less important reason, was the fact that, except in the great plain of Lombardy, the railway routes traversed hilly country by means of heavy gradients eased by numerous long tunnels. In 1897 the Minister of Public Works appointed a Commission to investigate the question. The Commission recommended that experiments should be made with battery vehicles, with the 650-volt direct-current system; and with 3,000-volt alternating current on the three-phase principle.

Battery traction did not give encouraging results and was soon abandoned, but in 1901 the Milan-Varese line was converted to third-rail 650 volts d.c., and has given successful operation over the intervening 33 years. In 1902 a big step was made by the adoption of three-phase current at 3,400 volts 15 cycles on the Valtellina line, from Lecco to Colico, Sondrio, and Chiavenna. The conversion work was carried out by Ganz & Co., of Buda-Pest, in conjunction with the railway engineers; and a reduction in gross operating expenses, including interest and depreciation, of 12 per cent. was obtained compared with steam traction.

Overhead construction of three-phase lines at crossover road

After the nationalisation of the railways in 1905, attention was concentrated on the possibilities of electric operation, principally with a view to increasing the capacity of certain heavily-graded lines, and one of the most difficult of these, the Giovi line, leading out of Genoa to the north, and handling 80 per cent. of the freight traffic from that port, was electrified in 1910-11 on the three-phase system at a tension of 3,000 volts and a periodicity of 15 cycles. This current, and that used by the Valtellina line, were subsequently altered to the standard 3,600-3,700 volts 16⅔ cycles. The Giovi line has a maximum grade of 3·5 per cent., six tunnels, and numerous curves of 1,300 ft. radius, in the 14·5 from Sampier-

Three-phase electric locomotives and shed at Pistoia

darena to Ronco, which was the first section electrified. The line from Sampierdarena to Genoa and along the coast to Savona was converted in 1916. The section from Savona to Ceva had already been electrified in 1914 at 3,700 volts three-phase, in order to increase its capacity, and this followed the conversion of the line from Bussoleno to Bardonecchia, part of the main route from France to Turin, electric operation over which commenced in 1912 with three-phase current at 3,300 volts, since converted to the standard 3,700 volts. The extension on to the P.L.M. Railway at Modane was completed in 1914.

During the war, electrification of the lines centering on Turin was commenced, and by 1924 electric operation was in force between Turin and Genoa via the Giovi route, and in 1925-26 was extended southwards along the coast from Genoa to Leghorn. The three-phase system in the north of Italy received further important additions by the conversion of the Bologna-Pracchia-Florence line in 1927, the Sampierdarena-Alessandria and Bolzano-Brennero lines in 1929, and the Savona-Ventimiglia and Cuneo-San Dalmazzo lines in 1931, and finally of the Spezia-Fornovo line in 1933.

Meanwhile, in 1928, the electrification of the Benevento-Foggia line across the main backbone of the Apennines was commenced, but something of a revolution was effected by adopting direct current at 3,000 volts tension. Apparently this has given so much satisfaction that it was used for the 60-mile extension from Benevento to Naples, opened in 1931, and for the new Bologna-Florence *Direttissima*. It has now been adopted as a standard for new construction in those areas away from the Milan-Turin-Genoa Leghorn three-phase system. The year 1928 also saw another innovation in the introduction of three-phase current at 10,000 volts 45 cycles, thus overcoming the disadvantages of the low-tension low-periodicity three-phase system, without getting away from the complicated overhead apparatus. The line so electrified was that from Rome to Avezzano, and the extension on to Sulmona was brought into operation at the beginning of 1933.

The State Railways electrified mileage is completed by a number of low-tension d.c. lines, which are detailed in

Repairing three-phase overhead wires at Zoagli station

the accompanying table, and by the single-phase Domodossola-Iselle line, which, under the Simplon Convention, is worked by the Swiss Federal Railways. A number of private lines are electrified, and the more important of these, such as the North Milan, the Emiliana, the Rome-Viterbo, the Circumvesuviana, and the Valli di Lanzo, use direct current at 3,000-4,000 volts.

Last year, a programme of widespread railway electrification was announced by the Italian Minister of Communications. The scheme was drawn up in an endeavour to work the lines economically and to prepare for increased traffic in the future, and also to develop Italy's hydro-electric sources in preference to importing foreign coal, a vital matter in the defence of the country. The full programme covers the conversion of 1,637 route miles of double track and 1,076 route miles of single track, comprising the following lines:

(*a*) Completion of the electrification of the Milan-Reggio Calabria trunk routes via (1) Bologna and Florence, and (2) Genoa and Pisa.
(*b*) Cross-country line from Turin to Trieste.
(*c*) Completion of electrification between Genoa and the Simplon, and between Genoa and the St. Gotthard, via Milan.
(*d*) Completion of electrification of the Ligurian-Piedmontese system, and of the lines in Tuscany bounded by the Genoa-Leghorn line on one side and the Bologna-Florence *Direttissima* on the other.
(*e*) The Udine, Tarvis, Trieste and Fiume lines.
(*f*) The line from Bolzano to Bologna.
(*g*) All lines converging on Bologna.
(*h*) Conversion of Rome-Sulmona 10,000-volt three-phase to 3,000-volt d.c. for the sake of uniformity.

The estimated cost of the conversions detailed above is 4,200,000,000 lire, equivalent to £45,400,000 at par, and the work is to be divided into three sections, occupying four years each. The first section is already under way, with conversion work proceeding between Naples and Salerno, and the contracts have now been placed for the conversion of the Fiume and Trieste lines.

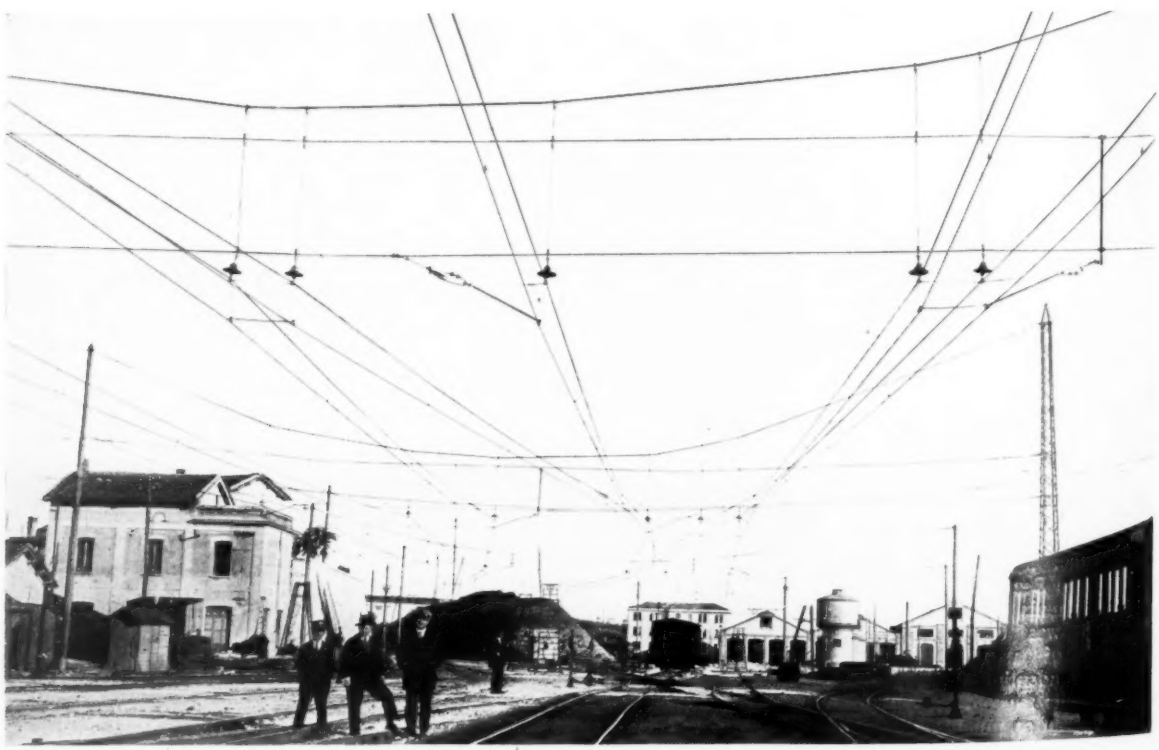
Power Supply and Transmission

The whole question of electric supply is controlled by the Italian Government as a matter of national importance, although a number of private companies are concerned in the production and transmission. The economic side of electricity supply favoured the linking up of the railway transmission system with others already in existence, and that the railways should have their own power stations only in certain cases where technical or out of the ordinary reasons should warrant the capital expenditure. In compliance with the general electrical policy the railway administration decided upon the application of 3,000-volt d.c. to the Benevento-Foggia line and 10,000-volt three-phase current at the industrial frequency of 45 cycles to the Rome-Sulmona section.

Oldest of all the railway-owned power plants is that at Morbegno on the Valtellina line, which was erected in 1901-02. Other hydro-electric stations are located at Bardonecchia, Pavanon and Sagittario, and there is also a steam power station at Chiappela, near Genoa. A number of private distribution companies also supply current for railway purposes. In general, the State transmission lines are of 60 kV., but tensions up to 150 kV. are used by certain supply companies.

LOW-TENSION THREE-PHASE SYSTEM

The three-phase network which covers Liguria and Piedmont is fed from various hydro-electric stations in the Alps and Apennines, and by steam power stations at Chiapella and Savona. Standardised substations are provided, containing four, seven, or nine single-phase oil-immersed transformers, the capacity varying from 600 to 1,750 kVA. The distance apart averages nine miles, but no greater distance than 20 miles is allowed, as the power of the three-phase motors falls very rapidly with a drop in the voltage. As a reserve to the static transformer substations, a number of mobile substations, each with a capacity of



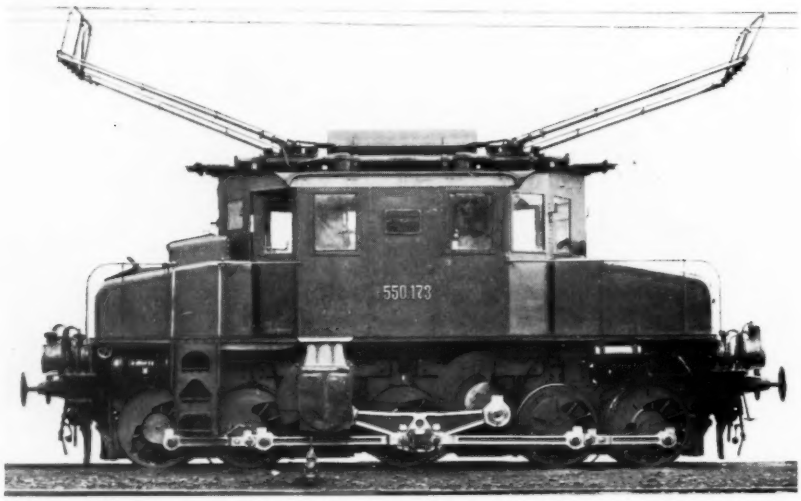
3,000-volt direct-current overhead lines at Benevento, Italian State Railways

Map of Italian electrified lines, showing various types of current used

2,250 kVA., are in service. These vehicles, which weigh 90 tons and run on two six-wheel bogies, step the current down from 60 to 3·7 kV., and experience has shown them to be so satisfactory that in some cases they are used instead of the ordinary type, being much cheaper to build.

New Lines

One of the most important divisions recently electrified on the three-phase system at 3,700 volts is the difficult line from Spezia to Fornovo, which is used by certain Rome-Milan expresses. Actually, the Fornovo line has a double junction with the Leghorn-Genoa line, at Vezzano and Sarzana, the former place being 5 km. distant from Spezia. The electrification of this line, with a route mileage of 59, involves the consumption of 20,000,000 kWh., and an annual saving of 40,000 tons of coal, and was carried out at a cost of 56,077,000 lire. A central substation has been erected at Pontremoli, which is operated by the supply company, and takes 60 kV. current from the Valtellina power plants, but the supply for the line is augmented from the Ozola, Predare, and Ligonchio electric centres which are connected to Aulla substation by two independent transmission lines. The railway-owned lines run from Aulla and Pontremoli to three further substations, all of which, except that at Fornovo, are of the outdoor automatic type. The Fornovo substation will ultimately



Standard E-type three-phase goods locomotive, Italian State Railways

house converting plant for the supply of the Bologna-Milan line when this is eventually electrified. The cost of electrifying the Spezia-Fornovo line amounted to approximately 1,000,000 lire per mile, but enabled the time between Milan and Rome to be reduced by an hour, and allowed heavier trains to be run.

Another new three-phase line of importance is the coastal extension from Savona to Ventimiglia, but full benefit from the electrification of the line from the latter place to Cuneo can hardly be felt until the short section passing through French territory is also electrified. Along the coast the maximum inclination is 0·9 per cent., but on the 11-mile section inland to Piena the average grade is 1·27 per cent. and the maximum 2·5 per cent. There are eight substations, at Piena, Ventimiglia, Taggia, Diano Marino, Albenga, Varigotti, and Lavagnola (Savona), and the whole conversion scheme cost 44,560,000 lire, apart from new rolling stock. It is now possible to travel right along the coast from Ventimiglia through Genoa to Leghorn, a distance of 209 miles, by low-tension three-phase electric traction, but this is exceeded by the 284 miles from Modane through Genoa to Leghorn.

HIGH-TENSION SYSTEM

The only line operating on high-tension industrial frequency three-phase current is the Rome-Avezzano-Sulmona line across the Apennines, the 64·25 miles from Rome to Avezzano of which were opened in 1928 and the remainder in 1933. There are grades as steep as 3·15 per cent., and the line contains numerous sharp curves. Power is supplied from the State Railways' plant at Sagittario, close to Sulmona, which has an annual output of 60,000,000 kWh., some of which, however, is used by the high-tension d.c. line from Naples to Foggia, and a small amount locally for general purposes. The increase in the periodicity of the current compared with that of the Ligurian-Piedmont three-phase system has led to geared motors being employed in the locomotives, although the Scotch yoke is retained for the final drive from the jackshaft to the wheels. On the 3,700-volt $16\frac{2}{3}$-cycle locomotives all the traction motors are gearless, the drive being of the type shown in the illustration at the top of this page.

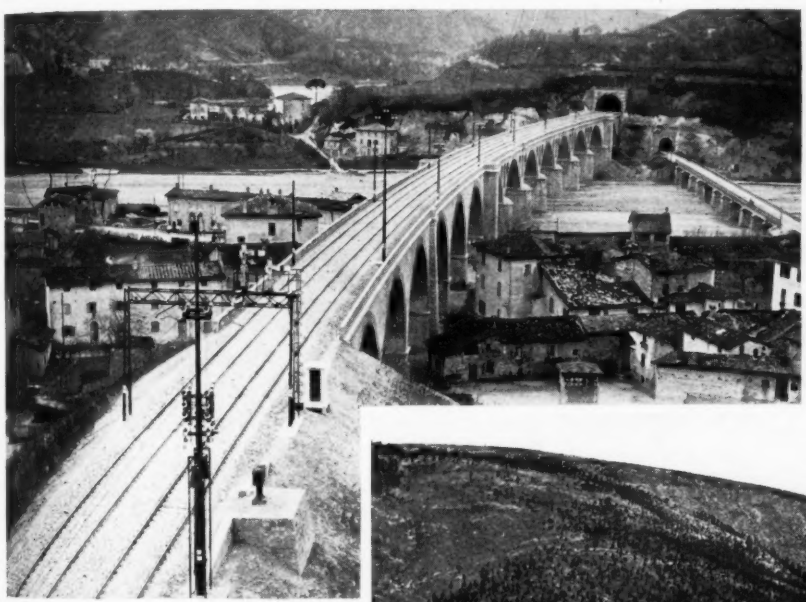
HIGH-TENSION D.C. LINES

The tenth anniversary of the Fascist march on Rome was celebrated in November, 1931, by the inauguration of a number of important public works, including the completion of the electrification of the Naples-Foggia main line on the high-tension d.c. system. The 63 miles from Benevento to Foggia were put into electric operation in 1928 and formed the first portion of the Italian State Railways on which 3,000-volt d.c. was used. The time for steam trains over the 123 miles from Naples to Foggia was 5 hr., and although a speeding up and increase in capacity would have been possible by doubling the line, the cost of this would have been excessive. When conversion work was being carried out, opportunity

Passenger train on the 3,000-volt direct-current Benevento-Foggia line

was taken to lay heavier rails, and improve the alignment in certain places, the combined result being the reduction in end to end time to 3½ hr. In steam days, 56 engines were required to handle the traffic, whereas 23 electric locomotives are now sufficient, and are able to haul roughly twice the weight at twice the speed over the maximum grade of 1 in 44.

The principal technical feature of the Naples-Foggia line is the use of mercury-arc rectifier substations, and the Benevento-Foggia section was probably the first main line in the world to be fed throughout by substations of this type, and the first line to use rectifiers for so high a tension. There are only six substations on the whole line, and the standard rectifier unit is of 2,000 kW. capacity, made up in banks of two or three units in the various stations.



Above: The Vado viaduct, which carries the Direttissima over the Vado valley and the Cassia national road

The maximum distance between the substations is 28½ miles, and the substations are fed with 118-kV. current from the Saggittario plant.

BOLOGNA-FLORENCE DIRETTISSIMA

By far the most important event connected with Italian electrification in recent years has been the completion, and opening on April 21, by the King of Italy, of the Bologna-Florence direct line, which has been under construction since 1913. The line is double track throughout, and has a maximum grade of 1·2 per cent., against the 2·56 per cent. of the old line via Pracchia, and the distance from Bologna to Prato, where the new line joins the old, is 52·2 miles compared with 73·4 miles by way of Pracchia. But due to the reduction in current consumption consequent upon the easier grades, the *Direttissima* is equivalent, on the current consumption basis, to a reduction of 48 per cent. in the mileage when going south from Bologna, and 38 per cent. in the northbound direction.

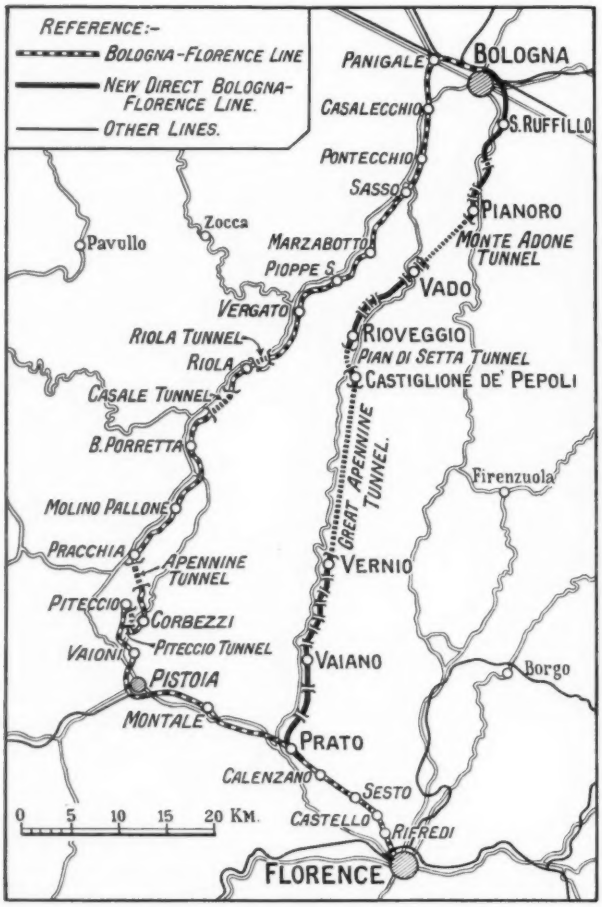
The importance of the *Direttissima* lies not so much in the saving of 21 miles of route or of a relatively large amount of current, but in the accelerations between Central Europe and Rome which are rendered possible. For instance, the present best time of 8¼ hr. over the 392 miles from Milan to Rome is an acceleration of 85 min. on the previous best timing over the 413½ miles of the old route. Together with improvements in connections at Milan, and the institution of several new Milan-Rome services, the cuts in long-distance journey times to and from Florence and the Italian capital will in several cases amount to 3½ hr.

As may be seen from the accompanying map, the *Direttissima*, on leaving Bologna, crosses the Savona torrent and continues on the right bank as far as Pianoro. The great massif of Monte Adone is negotiated by means of a 4½-mile tunnel, from which the line follows the Setta valley, runs through Pian di Setta tunnel, 1·9 miles, and then enters the chief work of the whole line, the great Apennine tunnel, 11½ miles long, second only to the Simplon among the world's railway tunnels. The summit level of the line, 1,072 ft. above sea-level, compared with the 2,034 ft. of the Pracchia line, is reached in the tunnel, from which the line falls to Prato, where the old route is joined. The line is entirely free from level crossings,

Below: Exterior of the new station at Prato, at the southern end of the Direttissima, which has replaced the old station nearby

but runs through 30 tunnels, with an aggregate length of 22·9 miles, and over 41 bridges and viaducts. Eight new stations have been built, including that at Prato, where the old station has been closed. The engineering features of the line were illustrated and described in THE RAILWAY GAZETTE for May 22, 1931.

Although shorter than the Simplon, the Apennine tunnel is of much greater cross-section, as one bore houses both tracks, the section being 29 ft. by 26 ft. against 16·5 ft. by 19·5 ft. There is a station in the middle to enable fast trains to overtake slower traffic. The excavated material amounted to 53,000,000 cu. ft., and the masonry lining to 15,500,000 cu. ft.; the electric current consumed

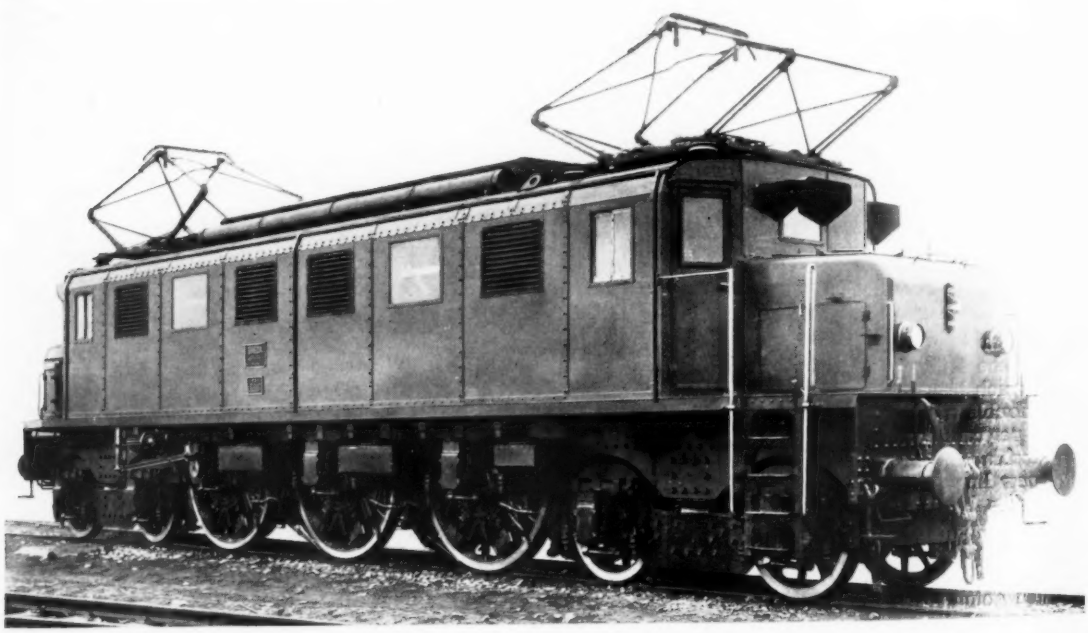


Map of Florence-Bologna Direttissima line

during the construction was 113,000,000 kWh., and the amount of dynamite, 981 tons. The total cost of the tunnel was 470,000,000 lire (£5,080,000 at par or £7,850,000 at the present rate of exchange), and that of the Setta tunnel 60,000,000 lire, or £650,000 at par, so

Passing station in the centre of the great Apennine tunnel under construction

that of the total cost for the whole line of 1,200,000 lire (£13,000,000 at par, and £20,000,000 at present rate), something like 65 per cent. has been required for tunnelling works. Moreover, the bridges and earthworks are very



3,000-volt direct-current express electric locomotive, Italian State Railways

ELECTRIFIED LINES OF ITALIAN STATE RAILWAYS

Line	Electrified Mileage		Voltage	System	Conductor	Year Electrified
	Route	Track				
Milan–Varese–Porto Ceresio	45·1	94·7	650	D.C.	3 R	1901–2
Lecco—Sondrio—Colico—Chiavenna (Valtellina)	65·0	77·0	3,700*	3 16⅔	O H	1902
Sampierdarena–Ronco (Giovi)	38·0	106·0	3,700	3 16⅔	O H	1911–15
Turin–Modane	69·0	166·0	3,700	3 16⅔	O H	1912–20
Savona–Ceva	28·0	48·0	3,700	3 16⅔	O H	1914
Lecco–Monza	22·7	40·0	3,700	3 16⅔	O H	1914
Sampierdarena–Savona	25·0	35·0	3,700	3 16⅔	O H	1916
Turin–Torre Pelice–Barge and Sangone–Chieri	61·3	88·8	3,700	3 16⅔	O H	1917–21
Turin–Ronco, Alessandria–Voghera, Tortona–Novi–Arquata	151·6	403·0	3,700	3 16⅔	O H	1921–24
Genoa Harbour	14·0	20·0	3,700	3 16⅔	O H	1924–26
Genoa–Leghorn	120·0	270·0	3,700	3 16⅔	O H	1925–26
Bologna–Piacchia–Florence	†77·0	138·0	3,700	3 16⅔	O H	1927
Bolzano–Brennero	55·0	141·0	3,700	3 16⅔	O H	1929
Sampierdarena–Ovada–Alessandria	45·8	60·0	3,700	3 16⅔	O H	1929
Cuneo–S. Dalmazzo, Piena–Ventimiglia	46·5	28·0	3,700	3 16⅔	O H	1930–31
Ventimiglia–Savona	67·0	77·0	3,700	3 16⅔	O H	1930–31
Fornovo–Sarzana–Vezzano	59·3	79·0	3,700	3 16⅔	O H	1932
Rome–Avezzano–Sulmona	108·0	150·0	10,000	3 45	O H	1928, 1932
Domodossola–Iselle‡	11·9	34·4	15,000	1 16⅔	O H	1930
Foggia–Benevento	63·0	93·1	3,000	D.C.	O H	1927–28
Benevento–Naples	60·0	123·0	3,000	D.C.	O H	1930–31
Florence–Bologna (Direttissima)	60·7	135·0	3,000	D.C.	O H	1934
Aosta–Pre St. Didier§	19·0	25·0	3,000	D.C.	O H	—
Naples–Villa Litorno	22·9	69·0	750	D.C.	3 R	1925–27
Trento–Male	37·0	41·0	800	D.C.	O H	1919
Brunico–Campo Tures	9·5	10·3	800	D.C.	O H	1919
Total	1,382·3	2,552·3				

* Originally 3,000 volts 15 cycles.
‡ Worked by Swiss Federal Railways.
† 87·5 miles until opening of Direttissima.
§ Purchased by State Railways in 1931.

heavy, so that only a small proportion of the total cost has been expended on electrification work.

Electrification

Electrification at 3,000 volts d.c. was decided upon as a result of experience gained on the Benevento-Foggia section. Three-phase current at 60 kV. is supplied to seven mercury-arc rectifier substations from Bologna distribution centre. The overhead contact lines are independent of one another, and are supported by side catenaries, with automatic tensioning devices. The old Florence-Bologna line, via Pracchia, was electrified on the 3,700 volt three-phase system in 1927, but the section from Prato to Florence has now been converted to 3,000 volts d.c.

The locomotives used on the *Direttissima* are all either duplicates or developments of those used on the Naples-Foggia division. Express passenger traffic is handled by 2-C_0-2 locomotives of class E.326, but a new 2-B_0-B_0-2 type is under construction for the heaviest work. Both types have double-armature spring-supported motors with the Bianchi form of quill drive. 1-D_0-1 locomotives of similar appearance, and classified as E.625, are used for goods trains. It may be of interest to record that the Metropolitan-Vickers Electrical Co. Ltd. in 1926 supplied complete electro-pneumatic control equipment for three of the 2,220 h.p. locomotives then being built for use on the Benevento-Foggia line, and one of these is shown at the head of a passenger train in the illustration at the bottom of page 822.

The latest type of express locomotive in actual service is illustrated on the opposite page. It is understood that locomotives of this type have recently been tested on the line at speeds varying from 90 to 95 m.p.h., although in normal service they will probably not exceed the usual maximum speed of 75 m.p.h.

The first table on the present stage shows that almost 1,400 route miles of State-owned line in Italy are now operated electrically, and it is anticipated that by the end of the present year another 50 miles will be converted. At the end of 1932, when approximately 1,260 miles of line were in regular electric operation, traffic was worked by 873 locomotives, and the lines fed through 105 substations with a total capacity of 483,000 kVA. Power was then produced in 24 power stations with a capacity of 357,200 kVA., and the h.t. transmission lines extended over a length of 3,000 miles. One-third of the power stations belonged to the State, and two-thirds to private companies.

On this electrified system, representing approximately 12½ per cent. of the total State-owned mileage, was carried one-third of the whole traffic. The total power consumption of 390,000,000 kWh. represented the equivalent of an annual saving of 590,000 metric tons of coal.

Tensioning device for contact lines as used on the Florence-Bologna Direttissima

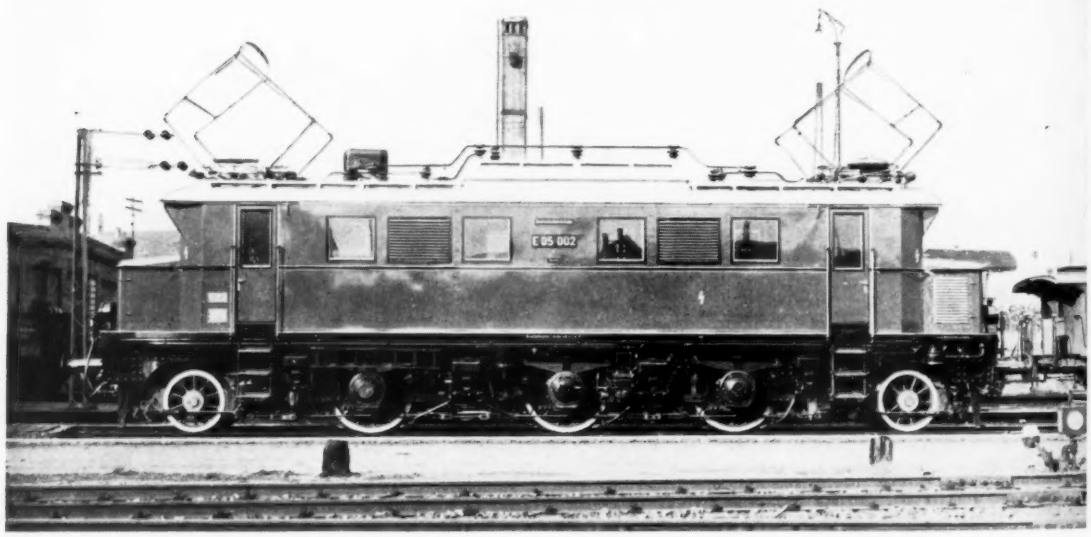
ELECTRIFIED PRIVATE RAILWAYS IN ITALY

Railway	Electrified Mileage		Voltage	System	Conductor	Year Electrified
	Route	Track				
North Milan: Milan–Saronno, Milan–Meda	31·0	80·0	3,000	D.C.	O H	1929
Emiliana	71·5	90·0	3,000	D.C.	O H	1930–32
S. Severo–Peschichi	49·0	55·0	3,000	D.C.	O H	1931
Voghera–Varzi	20·5	30·0	3,000	D.C.	O H	1932
Rome–Viterbo	65·0	70·0	3,000	D.C.	O H	1932
Rome–Ostia	16·0	?	3,000	D.C.	O H	1928
Turin–Ceres	26·5	40·0	3,600	D.C.	O H	1921
Central Umbria: Umbertide–Terni, &c.	70·5	85·0	11,000	1/25	O H	?
Other Lines (including light railways)	840·0	?	Various	Various	Various	1914–33
Total	1 190·0					

NOTES AND NEWS

Southern Railway Extension.—The opening to electric traction on May 1 of the Bickley-St. Mary Cray line, the first section of the Sevenoaks lines conversion scheme, brings the electrified route mileage of the Southern Railway up to approximately 361, and the track mileage to 982.

German Express Locomotive.—In addition to the class E04 single-phase express electric locomotive with individual axle drive, which we described in the issue of his Supplement for November 17, 1933, the German tate Railway has recently placed in service on the Bavarian division three locomotives of similar wheel arrangement and capacity, but with three nose-suspended motors. The to al output on the hourly rating is 2,950 h.p ;. the maximum speed, 81 m.p.h. ; the maximum axle load, 19·5 tons ; and the starting tractive effort, 39,650 lb. The total weight of 88 tons gives a weight per h.p. on the hourly rating of 66·5 lb. The main contractors for these locomotives were the Siemens-Schuckert-Werke, and the mechanical portions were constructed by Henschel & Sohn A.-G.



New express electric locomotive with nose-suspended motors, German State Railway

Electrification Possibilities in South Africa.—Mr. O. Pirow, the Minister of Railways and Harbours for the Union of South Africa, in introducing his railway budget on April 11, said that investigations were to be made during the coming year by departmental officers into the possibilities of further electrification schemes. Such conversion would be confined to districts having heavy traffic over steep gradients and to fast traffic involving frequent stops. The former condition applied chiefly in Natal, and the second mainly in the industrial area of the Witwatersrand and its extensions to Witbank and beyond.

Traction Motor Standardisation.—In the contract recently received by the English Electric Company from the Southern Railway for 136 traction motors for suburban stock and 136 motors for high-speed trains, it was felt desirable that these units should, as far as possible, be interchangeable with existing motors of Metro-Vick design and manufacture. To that end the two companies concerned have negotiated an agreement for the exchange of information, and co-operative developments on these lines between manufacturers should do much to encourage further railway electrification in Britain.

Russian Electrification.—The electrification of the Murmansk railway, conversion work on the first section of which was recently completed, was decided upon in view of the rapidly increasing traffic to the port of Murmansk. At the present rate of increase steam traction would have reached the limit of its capacity in another two years, after which the ruling gradients of the line would have had to be reduced from 1·45 to 0·92 per cent., necessitating very heavy earthworks. Electric working is not yet in full swing, as the first electric locomotive has just been turned out from the Kolomna works, but it is anticipated that a regular electric service will be in operation between Kandalaksha and Apatiti, 58 miles, at the beginning of 1935, and from Apatiti to Murmansk, 66 miles, at the beginning of 1936.

Dutch Electrification Extension.—A regular electric service on the extension of the 1,500-volt d.c. Amsterdam-Rotterdam electrification from the latter place to Dordrecht is to be inaugurated with the commencement of the summer timetables on May 15. The conversion embraces 12½ route-miles of double track, and a good deal of alterations and widening of the bridges carrying the line through Rotterdam were necessary. A further extension, over the 17½ miles of double track between Rotterdam and the Hook of Holland, has recently been sanctioned. No new rolling-stock is required for use over the Dordrecht extension, but additional stock will probably be built for the opening of the Hook of Holland line, which will most likely take place next year.